TITLE OF THE INVENTION

INSPECTION METHOD AND APPARATUS FOR CIRCUIT PATTERN

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a technique to inspect fine circuit patterns on circuit boards for semiconductor devices, liquid crystal displays, etc by using electron beams.

Description of the Related Art

As an example of related art, a typical existing method of inspecting the fine circuit pattern on a wafer (board) will be described.

An integrated circuit is made by printing the patterns formed on photo masks on a wafer successively by lithography and etching. The yield of IC's is affected by errors in printing patterns, entry of foreign matters, etc; accordingly, patterns on wafers are inspected in manufacturing process of IC's.

Defects of circuit patterns on wafers are detected mainly optically or by using an electron beam. With patterns ever becoming finer and more complex, shapes ever becoming more complex, and materials ever diversifying, it has become difficult to detect defects by optical methods. Proposed under the circumstances are methods of inspecting such

patterns on their images reproduced with electron beams, of which the resolution is higher than optical images.

According to some methods proposed, an electron beam is applied to a circuit board to obtain an image of its circuit pattern. When defects are detected, their images are stored and analyzed to determine the kinds of the defects automatically (for example, see Patent Document 1).

As an example, a typical existing method of measuring the dimensions of the fine circuit pattern on a wafer will be described.

As the circuit patterns of IC's become finer, more strict control of the dimensions and shapes of the circuit patterns on wafers is required. Even slight dimensional errors affect the performance of IC's.

Circuit patterns on wafers are measured optically or by using an electron beam. Electron beams are mainly used for the measurement of holes and measurement on two-dimensional images. According to some methods proposed, the top surface of the sample under inspection is charged with an electron beam and a first acceleration voltage and then a second acceleration voltage are applied to the sample to obtain an image for observation (for example, see Patent Document 2).

Patent Document 1: JP-A No.160402/1999

Patent Document 2: JP-A No.200579/2000

As described above, with the technique for inspecting and measuring circuit patterns with electron beams, quality control such as control of dimensions and detection of defects under higher lateral resolution is possible.

The existing inspection apparatus use a probe current of several ten nanoamperes and an electron beam accelerated to the range from several hundred volts to ten kilovolts, which pose not problems so long as silicon oxide or the like is used for insulating films between layers. With circuit patterns ever becoming finer and data-processing speeds of IC's ever increasing, however, it is becoming essential to use porous low-permittivity materials.

Although Patent Documents 1 and 2 claim that the acceleration voltage of an electron beam against a wafer is variable in the range from several hundred volts to ten kilovolts (in the case of an inspection apparatus) and several ten volts to two kilovolts (in the case of a length-measuring apparatus), they do not mention any art of inspection and measurement capable of reducing damage to resists and porous low-permittivity materials.

As described above, the prior art hardly addresses the problem of damage to circuit patterns to be caused by the exposure to electron beams. Accordingly, when wafers with circuit patterns including resists and porous materials are inspected, the resists and porous materials are damaged and

the dimensions of circuit patterns deviate from their design values.

The present inventor et al. ascertained that when wafers including resists and porous materials are inspected by the existing methods, the following damage occurs to wafers.

(1) Materials are decomposed and shrink. Patterns on wafers change under the exposure to electron beams and the reliability of measurement is reduced.

(2) Materials are decomposed by exposure to electron beams, which affects their characteristics such as adhesion to other materials.

The phenomena of the above paragraphs (1) and (2) lower the yield and performance of IC's.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a technique capable of reducing damage including shrinkage to resists and porous low-permittivity materials included in fine patterns on wafers while they are inspected with an electron beam.

The above object of the present invention can be achieved by optimizing the irradiation energy of an electron beam and limiting its irradiation density.

According to the study by the present inventor et al., the damage such as shrinkage and spoilage to a resist or porous low-permittivity material in a circuit board to be caused by an electron beam largely depends on the acceleration voltage of the electron beam relative to the board and the incident density of the beam into the board. The present inventor took porous low-permittivity materials (for example, porous low-permittivity hydrogensilsesquioxane (HSQ) materials) as examples and studied their shrinkage due to exposure to an electron beam to find that as the irradiation energy of the electron beam increased, their shrinkage increased, indicating their strong dependency on irradiation energy, and that their shrinkage tended to saturate as the irradiation density of the electron beam increased. Thus, the present invention is based on the new knowledge that the irradiation energy and density of the electron beam govern the damage to porous materials.

The present inventor et al. studied the shrinkage of the above porous low-permittivity materials under the changing probe current and changing irradiation density of an electron beam to find that the shrinkage hardly changed while the irradiation density was kept constant and the probe current was increased 5,000 times within the range of study. Thus, the present inventor et al. found that the

damage to a circuit pattern due to exposure to a primary electron beam could be reduced to an allowable range, regardless of the probe current of the beam, by controlling the irradiation energy and density of the beam.

The damage to a porous material due to exposure to an electron beam is caused by direct action between incident electrons and bonding electrons in the material or by thermal decomposition due to incident energy which raises the surface temperature of the sample. The present inventor et al. found that the former cause was predominant over the latter one while the probe current of the electron beam was kept constant.

The lower the irradiation energy of the primary electron beam is, the shallower the incidence of the beam is and thus the smaller the area of damage due to exposure to the beam is. Besides, the efficiency of destruction by an incident electron beam can be considered dependent on the irradiation energy of the beam.

Accordingly, damage such as shrinkage and spoilage to resists and porous low-permittivity materials during inspection and length measuring can be reduced by reducing the irradiation energy and density of the primary electron beam. The control of irradiation density of an electron beam can be accomplished by adjusting the probe current, scanning

area, scanning speed, and number of times of scanning by the beam.

Now the typical configuration to materialize the method of and apparatus for inspecting circuit patterns according to the present invention will be described.

(1) According to the invention, there is provided a method of inspecting a board with a circuit pattern including at least a porous low-permittivity material (for example, a porous low-permittivity hydrogensilsesquioxane material) or a material similar to it in terms of structure or composition. The method comprises a step of scanning the circuit pattern with a primary electron beam, a step of detecting secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a step of transforming the signals into an image, displaying the image, and inspecting the circuit pattern. Damage including shrinkage to the circuit pattern by the primary electron beam is reduced by controlling the irradiation energy and density of the primary electron beam.

(2) According to the invention, there is provided the method of the above paragraph (1), wherein the shrinkage of the damage to the circuit pattern due to the exposure to the primary electron beam is reduced to 2.4 nm or less by setting

the irradiation energy of the primary electron beam to 300 eV or less.

(3) According to the invention, there is provided the method of the above paragraph (1), wherein the irradiation density of the primary electron beam is limited according to the irradiation energy of the primary electron beam and depending on the kind of said low-permittivity material or said similar one.

(4) According to the invention, there is provided the method of the above paragraph (1), which further comprises a step of recording the irradiation history of the board such as the irradiation energy, probe current, and irradiation density of the primary electron beam and the areas of the circuit pattern to be exposed to the primary electron beam.

(5) According to the invention, there is provided the method of the above paragraph (1), which further comprises a step of finding, in advance, for each material included in the board, the correlations between (i) parameters including the irradiation energy, probe current, and irradiation density of the primary electron beam and (ii) dimensional changes of the circuit pattern and a step of adjusting at least one of the parameters before the circuit pattern is scanned with the primary electron beam.

(6) According to the invention, there is provided the method of the above paragraph (1), wherein the irradiation

density of the primary electron beam is controlled by (i) calculating, in advance, the maximum dose of irradiation per unit area in each area of the circuit pattern to be exposed to the primary electron beam and (ii) limiting the irradiation density of the primary electron beam below the maximum dose of irradiation in said area during the inspection of the board.

(7) According to the invention, there is provided a method of inspecting a board with a circuit pattern including at least a porous low-permittivity material (for example, a porous low-permittivity hydrogensilsesquioxane material) or a material similar to it in terms of structure or composition. The method comprises a step of scanning the circuit pattern with a primary electron beam, a step of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a step of transforming the signals into an image, displaying the image, and inspecting the circuit pattern. The shrinkage of the circuit pattern due to the exposure to the primary electron beam is reduced to 2.4 nm or less by setting the irradiation energy of the primary electron beam to 300 eV or less.

(8) According to the invention, there is provided a method of inspecting a board with a circuit pattern

including at least a porous low-permittivity material (for example, a porous low-permittivity hydrogensilsesquioxane material) or a material similar to it in terms of structure or composition. The method comprises a step of scanning the circuit pattern with a primary electron beam, a step of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a step of transforming the signals into an image, displaying the image, and inspecting the circuit pattern. The shrinkage of the circuit pattern due to the exposure to the primary electron beam is reduced to 2.4 nm or less by (i) setting the irradiation energy of the primary electron beam to 300 eV or less or (ii) setting the irradiation density of the primary electron beam to 1.4 C/m^2 if the irradiation energy of the primary electron beam is about 800 eV or more.

(9) According to the invention, there is provided an apparatus for inspecting a board with a circuit pattern. At least the areas of the circuit pattern to be exposed to a primary electron beam include at least a porous low-permittivity material (for example, a porous low-permittivity hydrogensilsesquioxane material) or a material similar to it in terms of structure or composition. The apparatus comprises a means of scanning the circuit

pattern with the primary electron beam, a means of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a means of transforming the signals into an image, displaying the image, and inspecting circuit pattern. Damage including shrinkage to the circuit pattern by the primary electron beam is reduced by controlling the irradiation energy and density of the primary electron beam. Besides, the shrinkage of the circuit pattern due to the exposure to the primary electron beam is reduced to 2.4 nm or less by setting the irradiation energy of the primary electron beam to 300 eV or less.

(10) According to the invention, there is provided a method of inspecting a semiconductor device with a primary electron beam. The method comprises a step of scanning the circuit pattern of the board of the semiconductor device with the primary electron beam, a step of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a step of transforming the signals into an image and displaying the image. Before the fine circuit pattern of the integrated circuit is inspected with the primary electron beam, (i) the various conditions

(including the irradiation energy and the probe current of the beam, and the magnifying power for observation) of irradiation are set, (ii) the material included in the circuit pattern are identified, and (iii) the allowable level of damage to the material is set. Then, the maximum irradiation density to each inspection area of the circuit pattern is controlled on the basis of data on the correlations between (i) the irradiation conditions and the allowable damage level.

The above data are quantitative ones on the correlations between (i) the change of damage to a resist or porous low-permittivity material and (ii) the irradiation energy, the probe current, and irradiation density of the primary electron beam.

Preferably, included in the method of the above paragraph (10) are a step of registering the above data on correlations and a step of providing an optimal number of times of irradiation.

(11) According to the invention, there is provided a method of inspecting a semiconductor device with a primary electron beam. The method comprises a step of scanning the circuit pattern of the board of the semiconductor device with the primary electron beam, a step of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and

latter electrons and converting the electrons into signals, and a step of transforming the signals into an image and displaying the image. The integrated-circuit board includes at least a porous low-permittivity hydrogensilsesquioxane material or a material similar to it in terms of structure or composition. The shrinkage of the circuit pattern due to the exposure to the primary electron beam is reduced to 2.4 nm or less by (i) setting the irradiation energy of the primary electron beam to 300 eV or less or (ii) setting the irradiation density of the primary electron beam to 1.4 C/m^2 or less if the irradiation energy of the primary electron beam is about 800 eV or more.

(12) According to the invention, there is provided a method of inspecting a semiconductor device with a primary electron beam. The method comprises a step of scanning the circuit pattern of the board of the semiconductor device with the primary electron beam, a step of detecting the secondary electrons generated or the electrons reflected from the board due to the irradiation or both the former and latter electrons and converting the electrons into signals, and a step of transforming the signals into an image and displaying the image. The method further comprises a step of (i) loading the integrated-circuit board, (ii) displaying a picture to set the conditions of inspection to be outputted, (iii) inputting parameters including the kind

of the resist or low-permittivity material included in the board, the irradiation energy and probe current of the primary electron beam used in the inspection, and the magnifying power for observation, (iv) displaying the maximum number of times of irradiation at an inspection area on the circuit pattern, and (v) setting the actual number of times of irradiation.

The inspection art of the present invention has the following advantages over the related art.

(1) By setting the rated irradiation energy of a primary electron beam to 20-500 eV for porous materials, the damage can be reduced to such a degree that the damage can be ignored even in the case of integrated-circuit boards with nodes of 100 nm or less. Accordingly, integrated-circuit boards comprising materials unstable under irradiation such as porous materials can be inspected without damaging them, which the existing inspection apparatus (their irradiation energy is over 300 eV) are not capable of.

(2) Because the irradiation energy is low, only signals of secondary electrons emitted and electrons reflected from the surface of a sample are detected without being affected by secondary electrons emitted or electrons reflected from below the surface. Thus, the dimensions and

shapes of circuit patterns can be inspected with higher precision.

With the art of the present invention, the electro-optical system and other systems of an inspection apparatus are designed so that the optimal performance (for example, the diameter of the electron beam is minimized) can be derived with irradiation energy of 300 eV. Thus, measurement and observation with higher precision can be realized.

The rated irradiation energy of the existing methods of inspecting circuit patterns with an electron beam is 500 eV or more (including length measurement). If a porous material is exposed to an electron beam of typical irradiation density, shrinkage of 10 nm or so occurs. With the art of the present invention, however, the shrinkage of porous materials can be reduced to 1-2 nm by setting the irradiation energy of an electron beam to 300 eV or limiting the irradiation density of the beam. Thus, with the art of the present invention, integrate-circuit boards which includes porous materials and of which the nodes are 100 nm or less can be inspected.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a retarding-type scanning inspection apparatus by electron-beam irradiation used in the embodiment of the present invention;

Fig. 2 is a flowchart for describing a first embodiment of the present invention;

Fig. 3 is a flowchart for describing a second embodiment of the present invention;

Fig. 4 is a block diagram for describing a third embodiment of the present invention;

Fig. 5A shows the shrinkage of XLK film to which an electron beam was applied by using the apparatus of Fig. 1 and the existing electron-beam method of inspecting circuit patterns;

Figs. 5B and 5C show the shrinkage of XLK film to which an electron beam was applied by using the same apparatus and methods of inspecting circuit patterns according to the present invention;

Fig. 6A is a cross section of a porous low-permittivity material before an electron beam is applied by the existing method;

Fig. 6B is a cross section of the porous low-permittivity material to which an electron beam was applied by the existing method;

Fig. 6C shows the shrinkage of the porous low-permittivity material to which an electron beam was applied by the existing method;

Fig. 6D is a cross section of the same porous low-permittivity material to which an electron beam was applied by the method of the present invention;

Fig. 7 shows variations in shrinkage of a film according to the inspection method of the present invention and the existing inspection method; and

Fig. 8 illustrates an example of a specification screen of GUI command level functions in forming a recipe.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to drawings, embodiments of the method of and apparatus for inspecting circuit patterns of the present invention will now be described in detail.

First Embodiment

Fig. 1 is a schematic illustration of a typical retarding-type scanning inspection apparatus by electron-beam irradiation. The object of the present invention is to control the integrated number of times of irradiation of an primary electron beam at each inspection area based on the irradiation energy and probe current of the beam, magnifying power for observation, and the scanning

rate during inspection depending on the kinds of resists or porous, low-permittivity materials in order to prevent or reduce the damage to circuit patterns by irradiation of the primary electron beam.

The irradiation energy toward a semiconductor device (or an integrated-circuit board) under inspection can be change by the ordinary method of changing the acceleration voltage of electrons emitted from the electron gun. In the present invention, however, embodiments through a retarding-type inspection apparatus by electron-beam irradiation will be described.

When extraction voltage 3 is applied to between a field-emission cathode 1 and extractor 2, electrons 4 are emitted. Emitted electrons 4 are accelerated (or decelerated) between the extractor 2 and an anode 5 of ground voltage. The acceleration voltage of the electron beam (primary electron beam) 7, which passed the anode 5, corresponds to the accelerating voltage of the electron gun.

The primary electron beam 7 accelerated by the anode 5 undergoes scanning deflection by a condenser lens 14 and a scanning deflector 15. The deflecting intensity of the scanning deflector 15 is adjusted for the two-dimensional scan of the top of a sample 12 with the fulcrum of the center of an objective 16. The deflected primary electron beam 7 is accelerated by the post-deflection acceleration voltage

21 of an accelerating cylinder 9 provided in a passage of the objective 16. The primary electron beam 7 after the post-deflection acceleration is focused on the sample 12 by the objective 16. A generator 13 generates negative retarding voltage which is applied to the sample 12 to form a deceleration field between the objective 16 and the sample 12. After passing through the objective 16, the primary electron beam 7 is decelerated by the deceleration field and reaches the sample 12.

With the configuration described above, the acceleration voltage of the primary electron beam 7 at the time of its passing through the objective 16 is the sum of the acceleration voltage 6 of the electron gun and the post-deflection acceleration voltage 21, which is higher than the acceleration voltage at the time of incidence of the beam 7 into the sample 12 (the acceleration voltage 6 of the electron gun minus the retarding voltage 13). Accordingly, a finer electron beam (high spatial resolution) is obtained, compared with the primary electron beam 7 focused by the objective 16 under the acceleration voltage at the time of the incidence of the beam 7 into the sample 12. It is accomplished by the reduced chromatic aberration of the objective 16. If the acceleration voltage 6 of the electron gun is 10 kV, the post-deflection acceleration voltage 21 is 8 kV, and the retarding voltage

is 9.7 kV, the primary electron beam 7 passes through the objective 16 under acceleration voltage of 18 kV and the irradiation energy of the primary electron beam 7 at the time of incidence is 300 eV. The spatial resolution of this example is about 2.5 nm, whereas the resolution is 10 nm if the primary electron beam 7 with irradiation energy of 1 keV is focused by the objective 16.

To realize the damage-free inspection of resists or porous-type materials, the irradiation energy has to be reduced to 300 eV or less, or the irradiation density has to be limited. High spatial resolution of, for example, 3 nm or less with irradiation energy of 300 eV can be obtained with the above setting.

When the primary electron beam 7 is applied to the sample 12, secondary signals 11 are generated. The secondary signals 11 to be used are secondary electrons and reflected electrons. The electric field formed between the objective 16 and the sample 12 acts on the secondary signals 22 as an acceleration field; therefore, the secondary signals 22 are attracted into the passage of the objective 16 and rise through the passage under the action of the objective 16. After passing through the passage, the secondary signals 22 pass through the ExB deflector 11 and collide with a reflector 27. The reflector 27 is a conductive plate and has an opening in its center to let the

primary electron beam 7 through. The collision surface of the reflector 27 is coated with a material highly generative of secondary electrons, such as gold, by the vapor deposition method. The secondary electrons and reflected electrons of secondary signals 22 collide with the reflector 27 through almost the same path.

The secondary and reflected electrons of secondary signals 22 collide with the reflector 27 to generate secondary electrons 28, which are detected and converted into electric signals by a secondary-electron detector 25 and amplified by a preamplifier 31. A monitor 23 undergoes brilliance modulation by the output signals of the preamplifier 31 to produce a two-dimensional image synchronous with the primary electron beam 7. Alternatively, the output signals of the preamplifier 31 may be converted into digital signals by an analog-digital converter 32, and the digital signals are sent through a buffer 33 to an image storage 34 or 35. The secondary-electron detector 25 may be a semiconductor detector or an MCP (micro-channel plate). The images stored in the image storages 34 and 35 are sent through an image processor 36 to a defect detector 37, where the kinds and locations of defects are determined and recorded.

If the irradiation energy of the primary electron beam 7 is reduced to, for example, 300 eV or less, the control

of electrification of the top surface of the sample 12 becomes more difficult. To cope with this problem, an electrification-controlling electrode 17 is provided between the objective 16 and the sample 12. A power supply 24 applies appropriate voltage to the electrification-controlling electrode 17 to form an appropriate electric field between the objective 16 and the sample 12 and thereby control the quantity of the secondary signals 22 returning to the sample 12. Thus, the electrification potential of the top surface of the sample 12 can precisely be controlled.

The output signals of the secondary-electron detector 25 are synchronized with the scan signals of the primary electron beam 7 to display an image on an electron-beam scan image display and store the image in the data-processing unit 26 including storages. The data-processing unit 26 processes the image and determines and records the shapes and dimensions of the image.

An aperture diaphragm 8 is provided to control the opening angle of the primary electron beam 7, and an adjusting knob 10 is provided to align the aperture diaphragm 8 with the vertical center axis of the inspection apparatus. The reference numeral 18 indicates a mechanism for moving the sample 12 in the X and Y directions. An insulating plate 20 is provided on the mechanism 18. Provide

on the insulating plate 20 is a sample holder 19, which the retarding voltage 13 is applied to. When a sample 12 is put on the sample holder 19, the retarding voltage 13 is applied to the sample 12, too. The reference numeral 29 is a blanker. By applying blanking voltage 30 to the blanker 29, the primary electron beam 7 is deflected for collision with the aperture diaphragm 8; accordingly, the primary electron beam 7 is prevented from reaching the sample 12. Thus, the primary electron beam 7 is applied to the sample 12 only during the observation and irradiation of the sample 12. For example, while the conditions of irradiation are calculated and set, the primary electron beam 7 is prevented from reaching the sample 12 and hence the irradiation density of the primary electron beam 7 can precisely be controlled.

Referring to the flowchart of Fig. 2, a damage-free method of inspecting porous, low-permittivity materials according to the present embodiment will now be described.

Referring to a database, the kind of a resist or low-permittivity material included in an integrated-circuit board is designated (Step 42) and then selected is irradiation energy capable of damage-free inspection (Step 43). The electro-optical system is adjusted with the selected irradiation energy (Step 44). Referring to the optical or electron-beam scan image of the circuit pattern, an inspection area and the magnitude of the

probe current of the electron beam to be used for inspection are specified and the magnifying power for observation of the area is determined (Step 45).

In Step 45, the image (image "A") is stored in a storage if necessary.

Thereafter, the primary electron beam 7 is interrupted with the blanker 29 (Step 46), and the maximum number of times of irradiation is estimated at each inspection area and the locations of irradiation and the maximum number of times of irradiation are stored in a storage (Step 47).

If the estimated number of times of irradiation is smaller than the minimum number of times of irradiation to obtain an SEM (scanning electron microscope) image with a sufficient signal-to-noise ratio, the measurement is impossible (Step 48). In this case, the system returns to Step 45 to specify an inspection area, the probe current, and the magnifying power again and repeats Steps 44-48. If the measurement is possible in Step 48, the system advances to Step 49, where if it is necessary to change the irradiation energy, the system returns to Step 43 and repeats Steps 43-49.

If it is not necessary to change the irradiation energy in Step 49, it is checked whether charging process to raise the yield of secondary signals is necessary or not

(Step 50). If the processing is not necessary, the blanker 29 is turned off (Step 55), the inspection area is measured at its specified magnifying power (image "B") (Step 56), and the result is reported (Step 57).

If a primary electron beam 7 with higher irradiation energy is applied to a sample 12 for higher spatial resolution, the irradiation density of the beam 7 is limited to reduce damage to the sample 12.

If the top surface of the sample 12 has to be charged before inspection, the primary electron beam 7 is set to an appropriate level of irradiation energy and the charging process is made (Steps 51-53).

The irradiation density values of all the spots of the inspection area are added up and the measuring time is set so that the irradiation will not exceed its upper limit.

The dimensions and shapes of the circuit pattern are measured and checked on the image "B." If the inspection apparatus is automatically operated, data on the inspection area and conditions of inspection may be read from a database without manual observation and an image "B" of the inspection area may directly be recorded. The results of measurement and checkups of dimensions and shapes on the image "B" are compared with data in the database for judgment.

Thereafter, the system moves to another inspection area and the above process is repeated. The above process is stored as a program in the system, and the program is executed.

Second Embodiment

Referring the flowchart of Fig. 3, a second embodiment of the damage-free inspection method according to the present invention will now be described. As the configuration of the inspection apparatus for this second embodiment is the same as that for the first embodiment, the description of the apparatus is omitted here.

The shrinkage of porous low-permittivity HSQ materials under irradiation tends to saturate as the irradiation density of the primary electron beam increases. If the irradiation energy of the primary electron beam is sufficiently low, monitoring of irradiation density of the primary electron beam during inspection is unnecessary so long as the effects on the performance and yield of integrated-circuit boards are at such an insubstantial level as can be ignored if the shrinkage of a porous material becomes steady.

In this embodiment, by designating the kind of the porous material included in the sample 12 (Step 58), such damage-free irradiation energy is provided (Step 59).

Thereafter, as in the case of the first embodiment, the electro-optical system is adjusted with the selected damage-free irradiation energy (Step 60), and while looking at the scan image of the sample, the operator marks an inspection area and determines the magnifying power for the observation of the area (Step 61).

Then, the dimensions and shapes of the circuit pattern in the inspection area are manually or automatically measured and checked and the results are stored. As in the case of the first embodiment, if the top surface of the sample 12 has to be charged before measurement, the charging process is made (Step 63-65).

Third Embodiment

Referring to Fig. 4, the third embodiment of the method of inspecting the circuit pattern of an integrated-circuit board including a resist or a porous material is now described. The inspection apparatus used in this third embodiment is similar to that used in the first embodiment and indicated by the sections surrounded by the broken line of Fig. 4. The reference numerals 71, 72, and 73 are a control system, a body tube, and a wafer chamber including a stage, respectively.

Data including information on the inspection areas of the circuit pattern of a manufacturing step are read in advance into the measuring apparatus from another storage

70 including a database of the circuit patterns of manufacturing steps of the integrated-circuit board. When an inspection area of the circuit pattern is selected from the data, the measuring apparatus directly generates an electron-beam scan image of the inspection area and measures the dimensions and shapes of the circuit pattern on the image. Thus, irradiation can be confined to inspection areas and hence the damage to the board due to the inspection can be minimized. The process of inspection is similar to those of the first and second embodiments (Figs. 2 and 3). As to the information on inspection areas of the circuit patterns of manufacturing steps of the integrated-circuit board, data obtained by other measuring apparatus may be read into the above measuring apparatus.

Fig. 5A shows the shrinkage of XLK film to which an electron beam was applied by using the apparatus of Fig. 1 and the existing electron-beam method of inspecting circuit patterns. Figs. 5B and 5C show the shrinkage of XLK film to which an electron beam was applied by using the same apparatus and methods of inspecting circuit patterns according to the present invention. The measurements shown in those figures were taken with an AFM (atomic force microscope).

The irradiation density is the same (17.7 C/cm^2) through the three cases. The shrinkage was about 5 nm in

the case of the existing method (the irradiation energy was 800 eV) as shown in Fig. 5(a), whereas the shrinkage hardly occurred in the cases of the methods of the present invention (the irradiation energy was 300 eV and 200 eV) as shown in Figs. 5(b) and 5(c). Thus, the methods of the present invention proved to be capable of reducing damage such as dimensional variation of circuit patterns due to inspection in which an electron beam is used.

Fig. 6 shows the result of observation of a cross-sectional profile of a sidewall of a bare hole, the sidewall being made of a low-permittivity material, by an SEM (with low irradiation energy) before and after applying an electron beam to a wafer including the low-permittivity material as an inter-layer insulator film in its circuit pattern (bare hole) by using the apparatus of Fig. 1 and the existing electron-beam method of inspecting circuit patterns.

When an electron beam was applied by the existing method (irradiation energy was 800 eV) to the profile of the sidewall before the electron beam irradiation (Fig. 6A), a primary electron beam or a secondary signal therefrom enters the low-permittivity material of the sidewall (Fig. 6B), causing the material to shrink (Fig. 6C).

Contrarily, when the measuring method of the present invention is used in the device of the first embodiment,

shrinkage was hardly observed after the inspection of the same pattern (Fig. 6D).

In Fig. 7, under each irradiation energy of the primary electron beam, the shrinkage of a porous HSQ film according to the change of irradiation density is shown. We see that the shrinkage of the film largely depends on the irradiation energy of the primary electron beam and tends to saturate as the irradiation density of the electron beam increases.

When irradiation energy of 1,000 eV was applied to the porous HSQ film by the existing electron beam inspection method, at typical irradiation density "a," the shrinkage of the film was "b."

Contrarily, when the measuring method of the present invention was used in the device of the first embodiment, since the allowable level "d" of shrinkage was set in advance, the inspection could be executed such that the shrinkage of the film due to the inspection did not exceed "d" in which the irradiation density was "c" or lower. Further, the shrinkage of the film due to the inspection was reduced to "d" or less by setting the irradiation energy of the primary electron beam to 500 eV and 300 eV.

As an example of the inspection according to the present invention, Fig. 8 shows a specification screen of GUI (Graphical User Interface) command level functions for

setting the inspecting conditions when forming a recipe. On this screen, names of parts and their functions are as follows.

(1) Component Box for selecting kind of resist/low-permittivity material: Select name of resist/low-permittivity material to be hit by the electron beam on the semiconductor device to be inspected from among items in the component box.

(2) Component Box for selecting shrinkage allowable level: Select the maximum value of shrinkage due to electron beam irradiation from among items in the component box in accordance with the specification of a semiconductor device.

(3) Component Box for selecting electron-beam irradiation energy: Select irradiation energy of the primary electron beam used in the inspection from among items in the component box.

(4) Component Box for selecting magnifying power for observation: Select a scanning range (magnifying power for observation) of the primary electron beam in the inspection from among items in the component box.

(5) Component Box for selecting probe current: Select the probe current value of the primary electron beam used in the inspection from among items in the component box.

(6) Set Button: When this button is pressed, inputted data in Steps (1)-(5) become effective, and the component box on the right for selecting the number of frames to be irradiated is enabled.

(7) Component Box for selecting the number of frames to be irradiated: Out of items in the component box, select the number of times of irradiation to each inspection area under inspection from among the available numbers of frames to be irradiated that are calculated in Step (6).

(8) OK Button: When this button is pressed, the inputted data in Step (7) becomes effective.

(9) Form Recipe Button: When this button is pressed, a screen for forming a recipe for the inspection is generated and displayed.

(10) Clear Button: When this button is pressed, the inputted data in Steps (1)-(5) are cleared and reentrant procedure becomes possible.

(11) Cancel Button: When this button is pressed, even if the OK button of (8) has been already pressed the inputted data in Step (7) is abandoned, and reselection becomes possible.

(12) OK Button: When this button is pressed, the contents that have been set in the regions A and B become effective, and the system goes to the next step of the recipe formation.

(13) Cancel Button: When this button is pressed, all the data inputted in the regions A and B are abandoned, which makes it possible to input conditions from scratch.

Action/processing and contents of the processing are as follows:

1) Construction of recipe forming screen (9)

Contents of Processing: (a) Generate a screen (b) Enable region A of the screen for inputting conditions

2) Input of inspecting conditions (1)-(6)

Contents of Processing: (a) Select the kind of resist or low-permittivity material in the semiconductor device, allowable level for shrinkage of materials caused by the electron beam irradiation, the irradiation energy and probe current of the primary electron beam, and the magnifying power for scanning during the inspection. (b) Read data on the correlation between the conditions of irradiation of the electron beam stored in the device in advance and the shrinkage of the material to be inspected, calculate the number of frames in which the same inspection area can be irradiated during the inspection, and store such data in the storage. (c) Disable region A and enable region B.

3) Input of the number of frames in which the same inspection area can be irradiated during inspection, (7)-(8), and (12)

Contents of Processing: (a) Input the number of irradiation frames calculated in Step 2) which are usable in the inspection. (b) Put away the screen for inputting conditions, and generate/display the next setting screen necessary for the inspection.

As described above in detail, according to the present invention, with respect to objects which have been immeasurable such as a pattern on a semiconductor device including porous low-permittivity materials such as an ArF resist material, a porous low-permittivity hidrogensilsesquiozane (HSQ) material and the like, damage-free or damage-reducing measurement in measuring the dimensions and shapes, detecting defects and reviewing becomes possible. Thus, the damage to the semiconductor device due to the inspection itself can be minimized, the information closer the actual state of the semiconductor device can be obtained, and the inspection can be performed with higher precision and reliability by using an electron beam of low acceleration voltage.